REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
19-03-2017	Conference Technical Paper	19 Mar 2009 – 26 July 2010

4. TITLE AND SUBTITLE

Binocular Multispectral Adaptive Imaging System (BMAIS)

5a. CONTRACT NUMBER
FA8650-10-C-6109

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
65502F

6. AUTHOR(S)

Wesley Sheridan

5d. PROJECT NUMBER
3005

5e. TASK NUMBER
RC

5f. WORK UNIT NUMBER
H02N (3005RC42)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Sage Technologies Ltd
1 Ivybrook Blvd Ste 190
Warminster PA 18974-1779

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Air Force Materiel Command
Air Force Research Laboratory
711 Human Performance Wing, Airman Systems Directorate
Warfighter Interface Division, Battlespace Visualization Branch
Wright-Patterson AFB OH 45433-7022

10. SPONSOR/MONITOR'S ACRONYM(S)

USAF AFMC 711 HPW/RHCV

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

DISTRIBUTION STATEMENT A. Approved for public release: distribution is unlimited.

13. SUPPLEMENTARY NOTES

88ABW Cleared 7/19/2010; 88ABW-2010-3866. Report contains color. Conference proceedings of the Institute for Defense & Government Advancement (IDGA) Night Vision Summit held in Arlington VA on 26 July 2010.

14. ABSTRACT

The Binocular Multispectral Adaptive Imaging System (BMAIS) is being developed as a replacement for night vision goggles that will also facilitate the integration of other sensor and systems that are part of the pilot's situational awareness in the cockpit and overall mission operational environment. The development approach is structured to accommodate the technology advances of the sensors and displays in order to realize the performance enhancements afforded by the technology evolution in those respective areas. BMAIS is a binocular helmet mounted imaging system that features dual shortwave infrared (SWIR) cameras, embedded image processors and dual electronic displays to present the imagery to the pilot. The system is ergonomically designed to be light weight with a component distribution to minimize the moment arm on the helmet. The unit supports sophisticated image processing with adaptive fusion, and the integration of external aircraft systems to include sensor imagery, embedded symbology and other aircraft/mission data. The system is fully digital allowing image enhancement algorithms and fusion of other sensor sites such as forward looking infrared (FLIR) and other aircraft subsystems. BMAIS is attached to the helmet via the standard banana clip on the HGU-55/P helmet.

15. SUBJECT TERMS

Binocular Multispectral Adaptive Imaging System, BMAIS, Shortwave Infrared, SWIR, Alternative Night/day Imaging Technologies, ANIT, Aircraft Helmet Image System, Digital Helmet Mounted Display, DHMD

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Darrel G. Hopper
Unclassified	Unclassified	Unclassified	SAR	30	19b. TELEPHONE NUMBER *(include area code)*

Binocular Multispectral Adaptive Imaging System (BMAIS)

Wesley Sheridan

Sage Technologies Ltd, 1 Ivybrook Blvd Ste 190, Warminster PA 18974-1779

This is a reprint of a paper by Sage Technologies Ltd (STL) and included in the proceedings of the Institute for Defense & Government Advancement (IDGA) Night Vision Summit held in Arlington VA on 26 July 2010. This work was performed under SBIR Phase I and II contracts FA8650-09-M-6960 and FA8650-10-C-6109 awarded to STL under the "AF083-015 Binocular Multispectral Imaging System (BMAIS)" program.

Key BMAIS requirements from the topic addressed by STL in this paper include:

Binocular (VNIR) SWIR System 40° FOV

100% Overlap with 1:1 magnification

Image Resolution:

Threshold	640 x 512 px
Intermediate	1280 x 1024 px
Objective	2560 x 2048 px

Frame Rate: 30 to 60 Hz (threshold to objective)

Supports inputs from aircraft-mounted sensors & computers

Space, Weight, Ergonomics & Power (SWEP):

Consistent with combat pilot helmet-mounted system

Mounts on standard aircrew helmet (HGU-55/P)

Night Vision Technology Application

Binocular Multispectral Adaptive Imaging System (BMAIS)

26 July 2010

Wesley Sheridan, Principal Engineer

Sage Technologies

BMAIS

Sponsor: SBIR contract, (FA8650-10-C-6109)

Wright Patterson Air Force Base

TPOC: Dr. Darrel Hopper, WPAFB

Human Effectiveness Directorate
Department of the Air Force
Wright-Patterson Air Force Base

Completed Phase I SBIR – December 2009

Initiated Phase II contract – May 2010

BMAIS

Objective:

Develop a helmet-mounted display (HMD) system for pilots that adaptively integrates shortwave infrared (SWIR), visible, near-IR (NIR), off-head thermal, and computer symbology/imagery into fused visualizations.

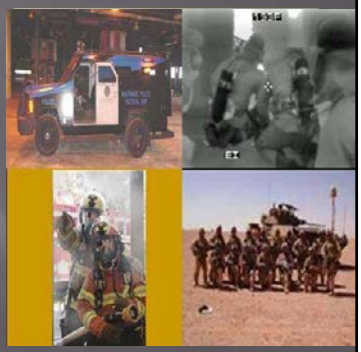
Goal:

Create and develop a revolutionary pilot HMD visualization system via a spiral development process leveraging recent advances in imaging sensors, fusion algorithms, and supercomputing processors.

SAGE

Corporate Profile

- **Veteran Owned small business incorporated over 25 years ago**
- **System Design and Integration (SDI) of infrared thermal imaging cameras, encrypted wireless digital video, and remote monitoring displays for military, night vision, security, law enforcement & surveillance applications.**
- **Provides System Engineering Services, Product Design, development and production**
- **System Engineering and Life Cycle Support for the Executive Transport Helicopter**



SAGE

Products that Reduce Warfighter vulnerability by improving Situational Awareness

LOW POWER ENVIRONMENTALLY HARDENED PORTABLE VISION ENHANCEMENT SYSTEMS

INTEGRATION OF VIDEO, LONG WAVE INFRARED (LWIR), AND SHORT WAVE INFRARED (SWIR) SENSOR TECHNOLOGIES

DEVELOPED SENSOR SHARING MODES THROUGH WIDE BAND DIGITAL WIRELESS COMMUNICATIONS

SAGE

Presidential Helicopter

AVIONICS ENGINEERING SUPPORT

VH-3D

VH-60

- NAVIGATION AND COMMUNICATIONS
- COMPUTER SYSTEM
- SYSTEM INTERFACES
- SOFTWARE DESIGN
- RADIO DESIGN
- SIMULATORS
- CONTROL PANELS

VH Program (1986 - 2010)

SAGE

Development Partners

Goodrich Corporation	SWIR Camera
Sarnoff	Image Processing
Gentex	Mounting, Ergonomics

BMAIS

What Are We Doing?

Replace Night Vision Goggles for pilots

Why?

- NVGs don't always work.
- They require a compatible cockpit for use.
- NVGs are not readily integrated.
- Preliminary analysis shows that more favorable size/weight/moment arm can be achieved with new solid state technology
- SWIR vs. NVG effectivity

BMAIS

Requirements

Binocular (VNIR) SWIR System
40° FOV
100% Overlap with 1:1 magnification
Resolution

Threshold	640 x 512
Intermediate	1280 x 1024
Objective	2560 x 2048

Mounts on standard aircrew helmet (HGU-55/P)
Supports computer input/other A/C systems

BMAIS – Phase II Application Development

Principle Effort:

Develop an Evaluation Tool to support the utility and effectiveness assessments of SWIR technology based imaging in the cockpit.

Support the experimentation and assessment of "SWIRology" as a means to broaden the application and effectiveness of night vision assisted systems, including the dusk/dawn transition phases of operational scenarios.

Ultimate Goal:

Replace the NVG with SWIR based imaging technology.

BMAIS

Why SWIR?

- Emergence of small, light weight and relatively low power sensors
- Range of response and extended response across the NIR and Vis bands of operation
- Wide dynamic range that can provide imagery from minimal night illumination to day light conditions
- Functional in situations that compromise NVGs such as: dust, fog, ambient light
- Imagery that is digitally based and can support image fusion efforts as well as inter system integration
- Potential for higher resolution, lower power, faster response without significant impact on size and weight

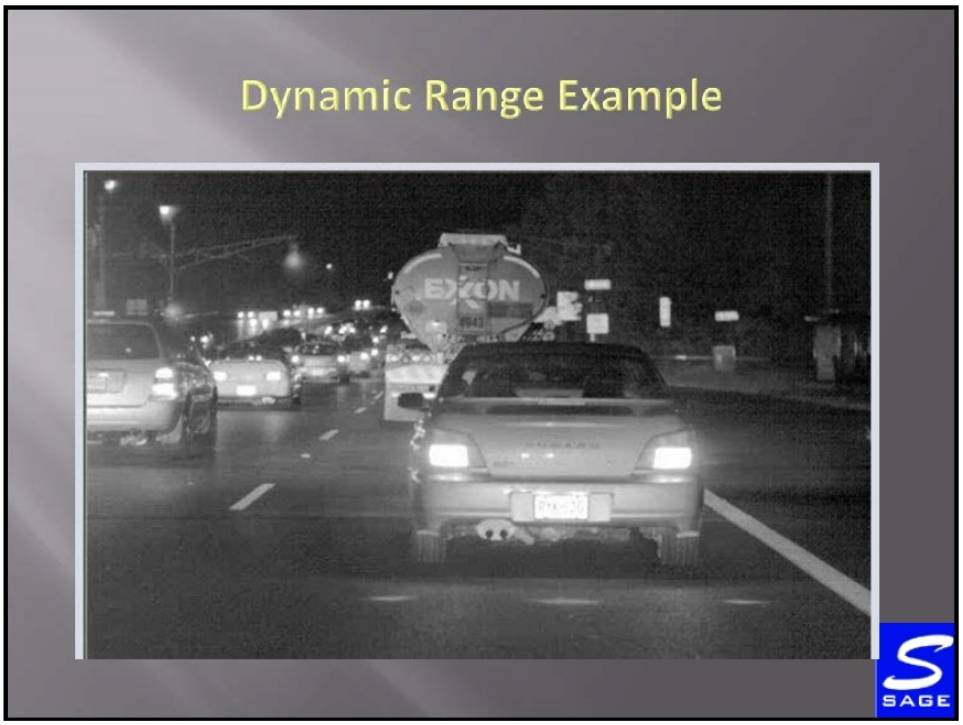
SAGE

BMAIS - SWIR SENSOR COMPARISONS

Photos Courtesy Goodrich

Littleton, e.t. al.

SAGE



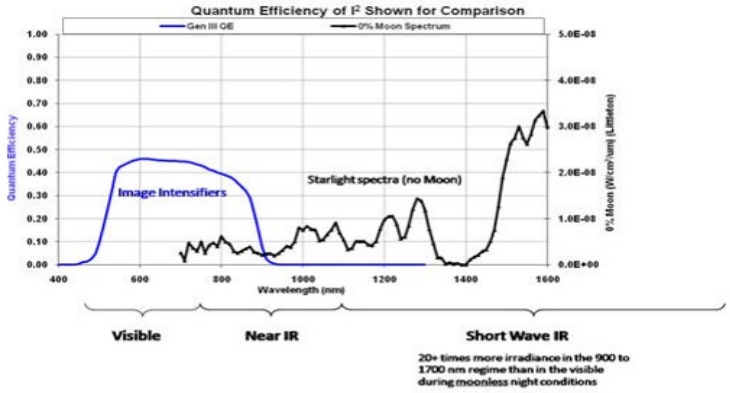
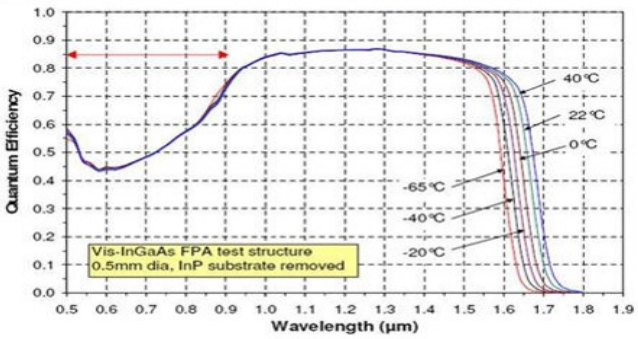


Figure 19: Night Sky Illumination Comparison of a Gen III I²QE to the measured night sky spectrum (Littleton). Visible, Near IR, and Short Wave IR spectral

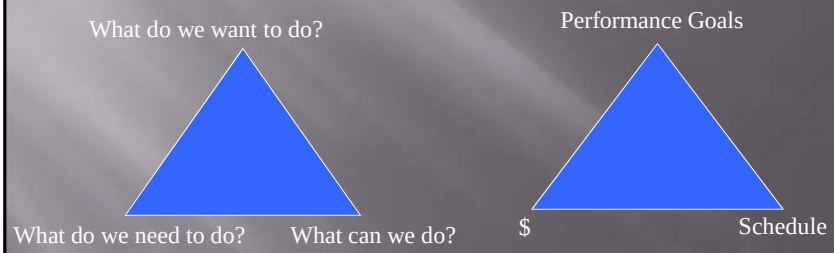


BMAIS

Why not just build a SWIR based NVG?

Application development is about 3-legged stools

Balance the goals vs. Constraints



BMAIS Functional Elements

It is not just the technology

Subsystems
- SWIR
- Processor
- Image Processing
- Display
- Controls/Updates/Expandability

SWEPI (Size/Weight/Ergonomics/Power/Integration)
- Mounting Concept
- Moment Arm
- Stowage/Deployment
- Design Concept
- User Adjustments

BMAIS

Requirements

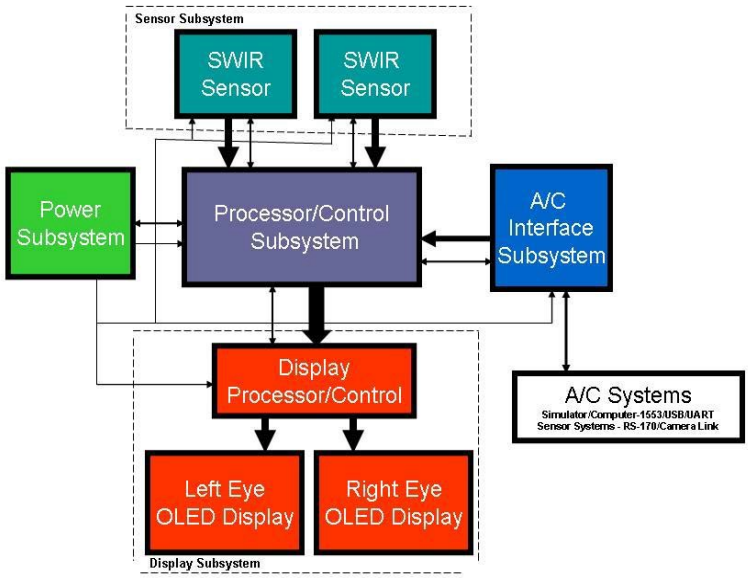
Binocular (VNIR) SWIR System
40° FOV
100% Overlap with 1:1 magnification
Resolution

Threshold	640 x 512
Intermediate	1280 x 1024
Objective	2560 x 2048

Mounts on standard aircrew helmet (HGU-55/P)
Supports computer input/other A/C systems

SAGE

BMAIS SYSTEM BLOCK DIAGRAM



SAGE

Subsystem:
SWIR
Processor
Image Processing
Display
Controls

SWIR CAMERA

Candidate Matrix – Substantial number of Cameras

Availability Filter

Threshold Performance (640 x 512)

SWEPI CRITERIA
- Suitable for Binocular
Helmet Mounted Application

SAGE

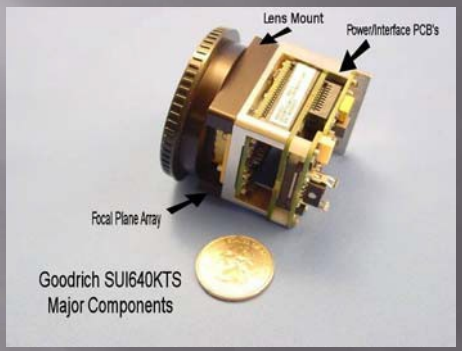
SWIR Camera

Preferred Options: (Size/Weight/Power advantages)

Resolution
Responsivity
Dynamic Range
Cockpit Compatibility
Near/Far Focus
Lighting
Colors

SAGE

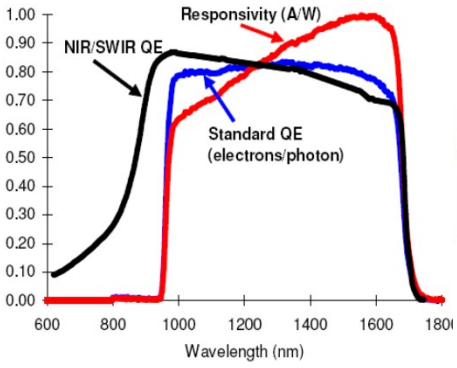
SWIR Camera Candidate

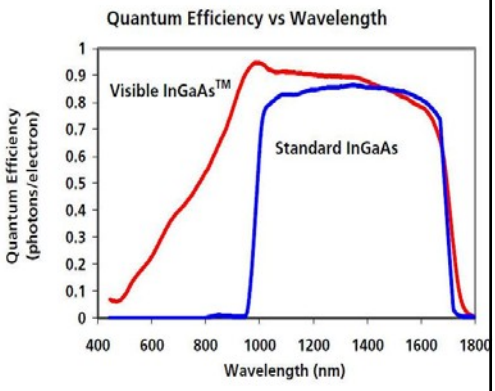


- Seeing in the light of night glow or night sky radiance
- Day-to-night imaging
- Covert illumination
- Able to see covert lasers and beacons
- 640 x 512 resolution
- Small size (2" x 2" x 1")
- Low power (~2W)

SAGE

Vis/NIR/SWIR Spectral Response





Goodrich SWIR Camera

SAGE

SWIR Candidate Performance Specifications

Goodrich – SU640KTSX-DR1-NIR-1.7R/RS170

Format	640 x 512
Pitch	25µm
Spectral Response	600nm – 1700nm
Mean Detectivity (cm*√Hz/W)	>1.5x10^{13}
Noise Equivalent Irradiance (photons/cm2*S)	<8x10^{8}
Noise (rms,electrons)	<125
Full Well (electrons)	1700k
Camera Core Size (MM)	42 x 38 x 41
Weight (g)	<90
Power (W)	2.5 - 6.0

SWIR Camera – Adaptation Potential

Interfaces:

- RS-170
- CameraLink®

PCB Stack:

- Unstack for mass redistribution

Power Management:

- Restrict operating environment
- Project use in TEC less configuration

SWIR Camera - Futures

Multiple 1280x1024 cameras in development

Reduced pixel size will afford similar size to 640x512

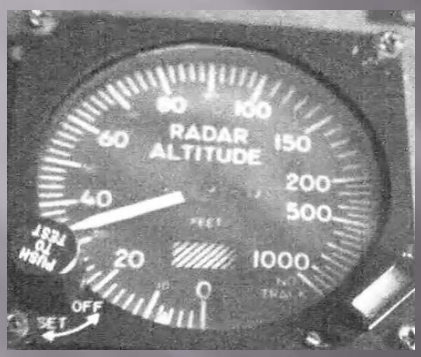
Lower power with scaled back or eliminated TEC

Decreased weight

Provide interface options to reduce board stack requirements

Potential to replace Electronics and Firmware with ACADIA Interface and Processing to reduce size/weight/power by eliminating redundant functions

SWIR vs. Visible Image



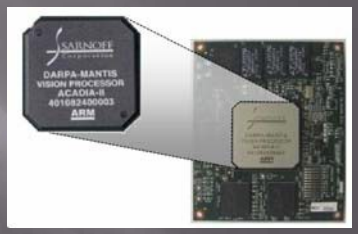
SWIR Camera (320x240 Res)
Minimum External Illumination

Visible Camera

BMAIS Processor

Subsystem:
SWIR
Processor
Image Processing
Display
Controls

ACADIA® II SOC is an advanced vision processing technology by Sarnoff, developed with support by DARPA under the MANTIS program.



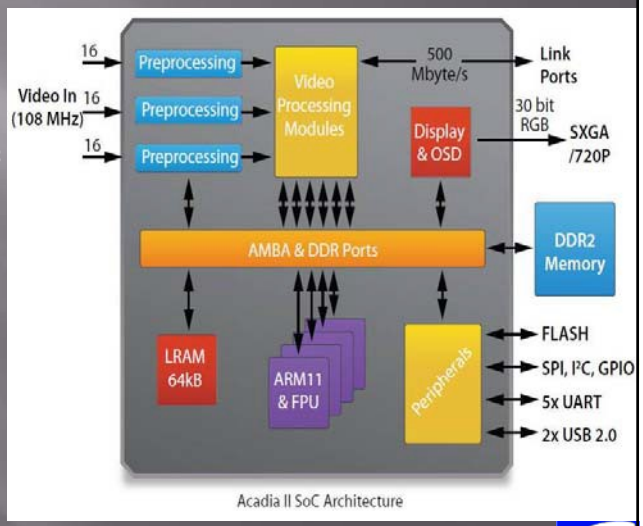
Capabilities:

- Three channel, pattern-selective adaptive fusion for night vision
- Real-time, low latency processing
- Full color, full resolution processing (up to 1280x1024 and 30/60Hz)
- Robust stabilization, multiple alignment models up to 1/10 of a pixel accuracy
- 1280x1024 RGB video output with on-screen display processor
- Four ARM®11 300MHz floating-point processors

SAGE

Acadia II Mezzanine PCB

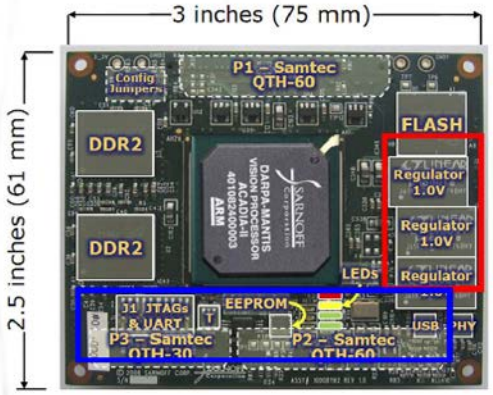
For BMAIS:
Low Power (<1W to 4W)
3 Digital Video Input Ports
Video Output Port
(30 Bit RGB)
USB Port
UART
I^2C



Acadia II SoC Architecture

SAGE

Acadia II Vision Module (Mezzanine Card)



P1-3 (Samtec) Connectors Provide:

- Power, Ground
- Clocks, Resets
- Video Inputs and Output
- I²C, SPI, and USB buses
- Link ports

J1 (Debug) Connector Provides:

- One UART connection
- Two JTAG interfaces
  - One for the ARM11TM MPCoreTM debug port
  - One for the Acadia II SOC test port

- On-board Flash, EEPROM, and DDR2
- High-speed DDR2 Signal Routes Solved
- Runs applications right "out of the box"
- Available for prototyping or production

BMAIS Processor

ACADIA II Mezzanine PCB (Part of Development Board)

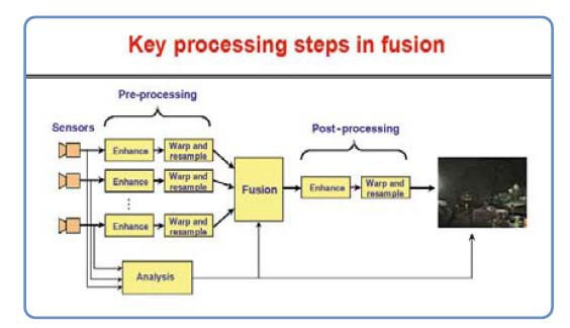
Sarnoff/ACADIA Software/Algorithm Support Package

VxWorks Kernel with the Software Package

VxWorks Development Station to be Acquired for BMAIS Custom Functions

Microprocessor/Controller to Support ACADIA Control/ Monitoring, External Communications, Boot-Up Configuration Control

Processor - Acadia II Fusion & Stabilization



Pre-processing
- Noise Reduction
- Histogram Normalization
- Geometric Correction – translation, rotation, zooming or shearing (align to 1/10 pixel)
- Stabilization – balance shaky imagery

Analysis – automatic adjustment of imagery based on real-time statistics
Fusion – Combine "best information" from all sources
Post-processing – Optimize contrast to match image display
Speed – full frame rate 30 to 60 frames per second (~ 2 frames latency)

SAGE

BMAIS Processor Futures

Readily Supports the Intermediate Level Performance Requirements:

1280 x 1024 Imagers

1280 x 1024 Displays

Excess processing capacity (4 ARMs)

Ongoing Image Processing Development

Objective Level :

2048 x 2048 at reduced frame rate

SAGE

ACADIA Processing Functions

Subsystem:
SWIR
Processor
Image Processing
Display
Controls

Optimized Processing Functions

- *Contrast Normalization (CN)*
- *Flat Field Correction*
- *Noise Reduction*
- *Warping*
- *Histograms*
- *Bayer Conversion*
- *Output Color Correction*

SAGE

Acadia II Automatic Detection & Tracking

Accuracy – down to 20 pixel targets
Filtered Imagery – resilient to sensor and environmental clutter and captures imagery at multiple scales (SWIR, Visible, LWIR)
Image to Image Alignment – compensates for operator helmet motion, detects residual motion
Continuous Background Modeling – maintains robustness
Disparity Detection & Verification – perceives differences between two aligned images, and substantiates based on target appearance, size, shape, and motion characteristics.

SAGE

BMAIS Custom Functions

Display Format and Drivers

OSD (On Screen Display) Support – Flight Data, Status, Alerts, Queues

External Interface Communications – Other Aircraft Data and Imagery Sources

System Controls/Operating Modes – Mission Specific Configurations and Processing Functions

Acadia II Processing Options

Parallax Correction

Unit can support a geometric correction algorithm that will provide the user with a display that presents an image on axis to the line of sight

Near Field Focus

Unit can implement Dynamic Multi-Modal Registration that allows automatic correction of overlap even at very close operating distances (2ft to 3ft)

Digital Zoom

A 2X to 4X digital zoom can be implemented with interpolation to allow a improved viewing of distant objects

BMAIS – Display Requirements

Subsystem:
SWIR
Processor
Image Processing
Display
Controls

The minimum performance requirements are defined as follows:

- Binocular configuration
- 40°FOV with 100% overlap-1:1 magnification
- 640x512 format with symbology overlay or synthetic or augmented imagery
- 30 to 60Hz frame rate
- SWIR only with computer input capability

Augmented mid term and long term performance would be:
1280x1024 to 2560x2048 pixels (20:20 in a 40°FOV)

BMAIS Display Candidates

Source	Type	Format	FOV	WT	Power	Interface
eMagin	OLED	852 x 600	42° with SVGA+ OLED	11g	200mW	RGB
Holoeye	LCoS	800 x 600	28° Lens Selectable	23g + lens	400mw +Illumination	RGB A or D
Lumus	Microdisplay Dependent (see through)	800 x 600	32° Expandable	70g	2-3W	RGB

Other candidates were also considered.

BMAIS Display Subsystem

Proposed:

eMagin 852 x 600 OLED with Prism Optic
- 39.5° FOV
- 22mm Focal Length

Drive From ACADIA
- RGB
- I^2C

WF05 Prism Optic
- eMagin OLED
- 800x600 format
- Nominal 42° FOV
- 22mm Focal Length
- Less than 11g

Potential Problem:

Left-Right microdisplay drive
Could see 1 frame delay between the images

SAGE

BMAIS Display Futures

Futures:

eMagin 1280 x 1024 OLED
Kopin 1280 x 1024 LCD
LCOS NTE & Projection Type
Other entries, e.g. mems based

SAGE

Subsystem:
SWIR
Processor
Image Processing
Display
Controls

BMAIS SYSTEM CONTROLS

Operating Mode

- SWIR Only
- External Imaging
- Symbology Overlay (OSD)
- System Set-Up
- Status Monitor
- Display Brightness

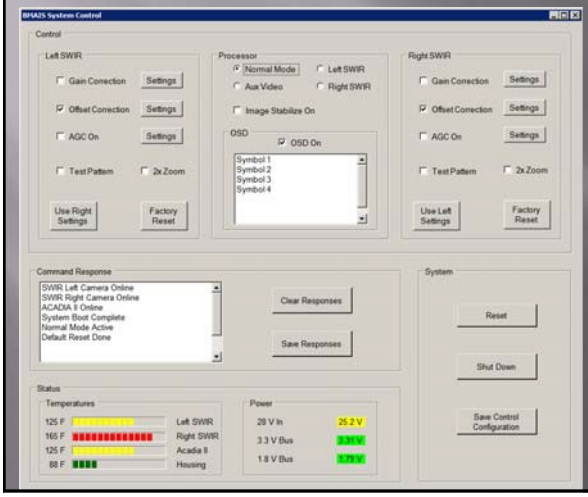
System Set-Up

- Camera 1 - 2 Operating Parameters
- Symbology Programming
- ACADIA Processing Set-UP
- ACADIA Algorithm Updates

SAGE

Operating Modes/Controls

PC based GUI driven set-up, control and status



Flexible

Scalable

Expandable

Legacy/Update Compatibility

SAGE

BMAIS Control Unit

Portable Control Computer (MR-1)

1.8” x 6.6” x 4.8” – 2.4#

5.6” WSVGA display – outdoor viewable

80 GB HDD or 64 GB SSD

Wireless options Multiple

I/O configurations Sealed keyboard, backlit

6 hour battery life MIL-STD 810F and 810G

SAGE

BMAIS Design Configuration Issues

Design Concepts
Section Views
Mass Distribution
Moment Arm Comparison
Cockpit Examples
Subunit Power/Weight Breakout

SAGE

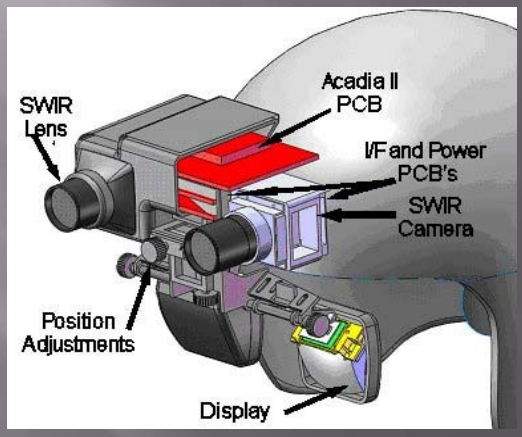
Example NVG Configuration

Design Concepts

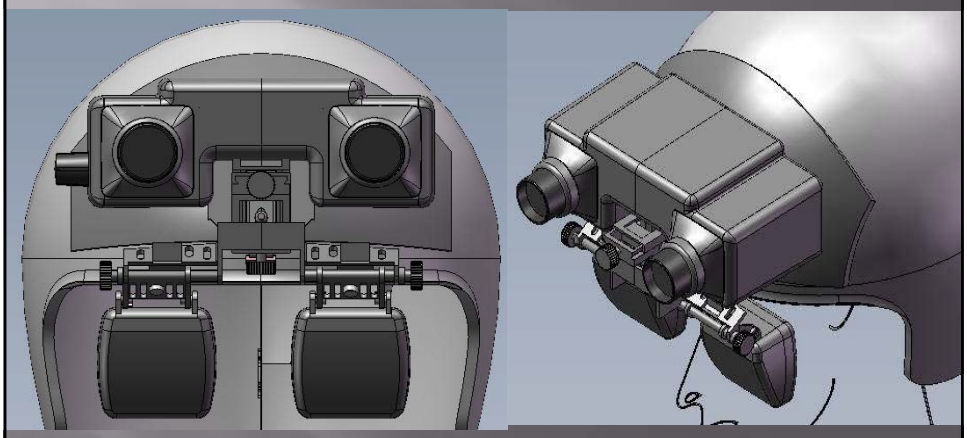
Proposal Concept:

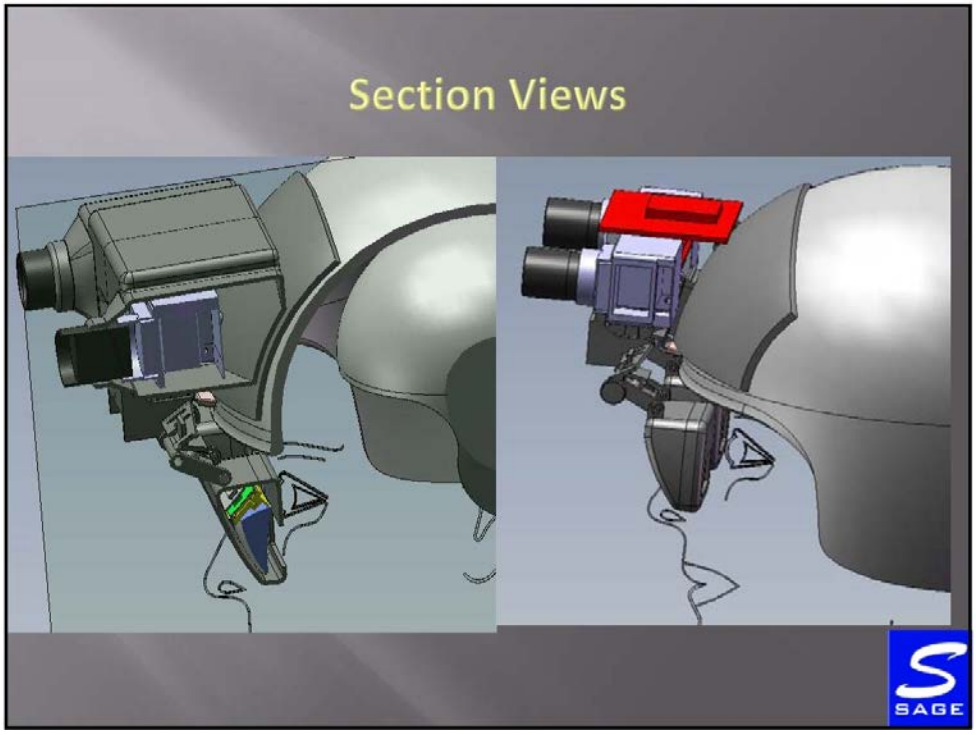
Alternative Concept:

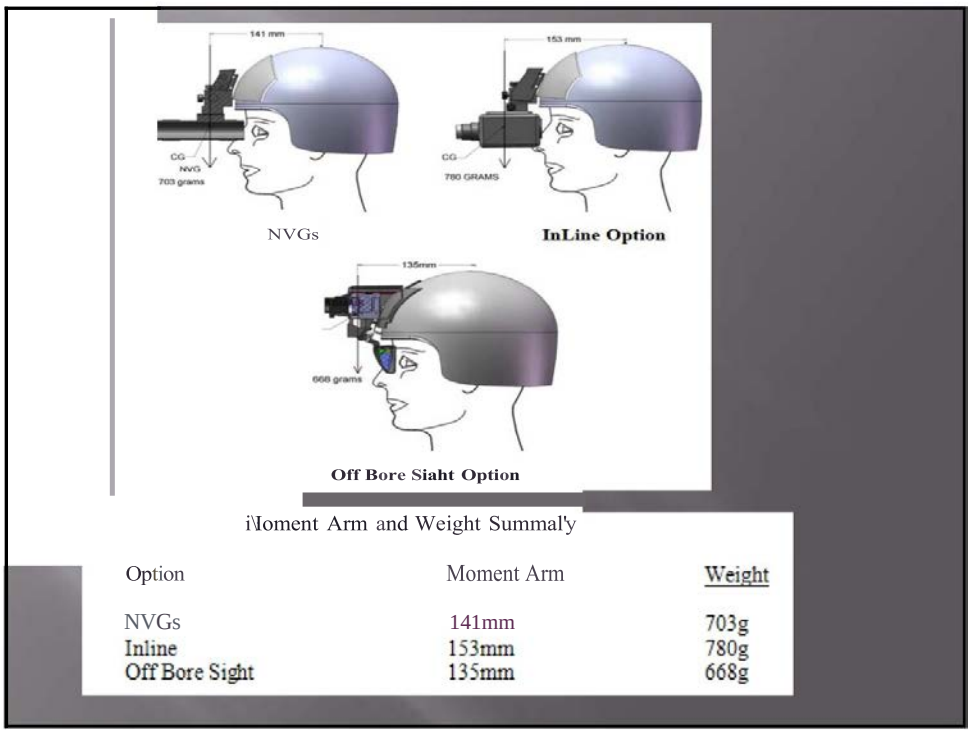
Concept Breakout



Subunit Distribution







i\Ioment Arm and Weight Summal'y

Option	Moment Arm	Weight
NVGs	141mm	703g
Inline	153mm	780g
Off Bore Sight	135mm	668g

Futures/Ancillary Issues

- Evaluation Platform and Scenarios
- Cockpit Adaptation Issues
- Related Developments
  - SWIR Camera
  - ACADIA Development
  - Integration Issues
  - Alternative Display Implementations

CDU Keyboards – New / Old

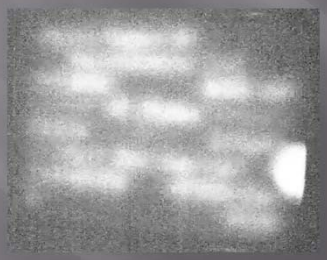
CDU-800X-5

CCD-814-10

Minimal External Illumination (320x240 Res) w/SWIR

CDU Displays – Old / New

CCD-814-10



CDU-800X-5

No Illumination (320x240 Res) w/SWIR

BMAIS Physical Characteristics

Sub-System/component	Weight(gm)	Power(mW)
Front End Optics (2 each per)	120	0
SWIR Camera Core (2 each per)	160	4,200
Processing Board	43	1,000
Power/Interface PCB	20	800
Display Chip (2 each per)	32	400
Display optics (2 each per)	50	0
Housing	150	0
Mounting	60	0
TOTALS	**635 (~22 ozs)**	**6,400**

BMAIS – GENTEX Support

Helmet Issues
- 3D Model
- Variations in dimensions/mass distribution
- Ergonomic analyses/studies/recommendations
- Helmet model types and variances
- HMD provisions/problems/issues

Mounting Issues
- Incremental mass distribution
- Weight/balance studies
- Force analyses under operational scenarios
  - Maneuvering
  - Take off/landing
  - Ditching
  - Eject/bailout

BMAIS Challenges

- Unit packaging/mounting for minimum weight and moment arm
- Power consumption within small form factor
- Ability to control hyperstereopsis with image translation
- Frame delay between left/right image display
- 30 Hz response of SWIR camera in a highly dynamic environment
- Compatibility of cockpit instruments, gauges, displays, indicators